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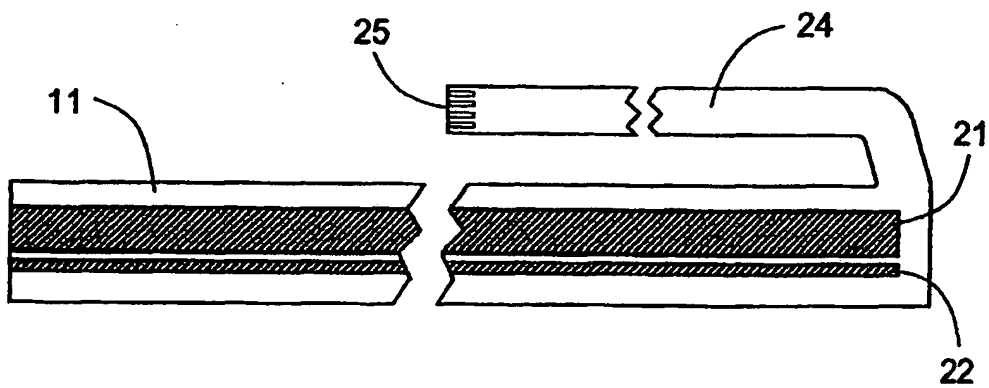
(54) Title: SONAR TRANSDUCER



WO 02/075356 A1

(57) Abstract: An improved transducer for a proximity sensing system using a sonar transmitter is disclosed. An autonomous device provided with a number of motor-driven wheels further comprises a number of elements for the proximity navigation and guiding of the device such as a microprocessor system and a proximity ultrasonic sensing system comprising at least one transmitting member and one receiving member. The transmitting member is formed by the ultrasound transducer (11), which is positioned behind a wire mesh at the front of the device. The device transmits ultrasonic waves from a first strip-shaped device (21) with a narrow vertical distribution within a wide horizontal sector, and a second strip-shaped device (22) providing a wider vertical distribution within a similarly wide horizontal sector in front of the autonomous device. The proximity sensing system comprises a number of microphone units provided with hollow pipes for the sound and forming a input portion of a receiving system for receiving echoes of the transmitted ultrasonic waves reflected from objects in the forward course of the moving device. With this arrangement of transmitting and receiving, echoes from the floor or ground as well for instance sharp edged carpets or the like will be heavily suppressed. This then gibes a much more simplified detection of objects in the zone near to the device, where echoes from a floor or ground and the device itself become very strong.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Sonar transducer

TECHNICAL FIELD

The present invention relates to a sonar transducer and more exactly an improved ultrasound transducer for an autonomous device for instance a self-navigating vacuum cleaner.

BACKGROUND

For many years there has been a desire to provide, for instance, an autonomous apparatus for floor treatment, particularly a vacuum-cleaner, which is controlled by a sensing system sweeping around the horizon in analogy, for example, with a ship radar. Then the desire is, that the apparatus should be able to navigate itself in a room, such that it, for instance, will be able to perform a cleaning function according to a predetermined pattern or a predetermined strategy and at the same time avoid colliding with different obstacles, which may be present in the room, besides avoiding collisions with the walls or other limitations of the room.

Several such systems are known to the prior art, two of which are disclosed in the International Patent Applications WO 97/41451 (U.S. Patent No. 5,935,179) and WO 00/38028. An embodiment of an autonomous apparatus according to the prior art generally consists of a main body, being supported on or by a number of motor driven wheels or rollers and further containing a set of sensors usually in combination with transmitters for navigation as well as obstacle detection. A microprocessor is together with appropriate software controlling the device and via output data controlling the transmitters and the motors of the device. The microprocessor receives input data from the sensors and the wheels. The wheels then are used for position information and the sensors for localization of wall limitations as well as localization of potential obstacles.

A disadvantage of the apparatus disclosed in WO 97/41451 will be due to a somewhat limited sonar range in some elevation directions and therefore some range limitations will result in the ability to detect potential obstacles.

Therefore there is a desire to find an improved transducer for the proximity sensing system utilizing the sonar system in, for instance, an automatic polishing or vacuum-cleaning operation, to then present an even better ability to find a clear way when performing its operation. The improved apparatus should also be simple and cheap to produce and thereby be able to still present an appealing price to customers.

SUMMARY OF THE INVENTION

According to the present invention a proximity sensing system is provided for a self-navigating device, particularly a vacuum-cleaner or dust-robot, which comprises a sonar transducer system. The present transducer presents a wide sonar pattern with a high directivity in the forward direction resulting in high sensitivity at the receiver but also at the same time a wide sensitivity in a vertical forward direction for detecting obstacles at heights interfering with the height of the autonomous device.

The present invention discloses an improved transducer for a proximity sensing system using a sonar transmitter. An autonomous device provided with a number of motor-driven wheels further comprises a number of elements for the proximity navigation and guiding of the device such as a microprocessor system and a proximity ultrasonic sensing system comprising at least one transmitting member and one receiving member. A mechanical sensing member is actuating at least one touch sensor if the device makes contact to an obstacle in the course of the moving device. The transmitting member is formed by the ultrasound transducer, which is formed at the front of the device. The device transmits ultrasonic waves from a first strip-shaped device with a narrow vertical distribution within a wide horizontal sector, and a second strip-shaped device providing a wider vertical distribution within a similarly wide horizontal sector in front of the autonomous device. The receiving member comprises a number of microphone units provided with hollow pipes for the sound and forming an input portion of a receiving system

for receiving echoes of the transmitted ultrasonic waves reflected from objects in the forward course of the moving device.

A proximity sensing system for an autonomous device according to the present invention is set forth by the independent claim 1 and further embodiments are set forth by the dependent claims 2 to 10.

A transducer for the proximity sensing system according to the present invention is set forth by the independent claim 11 and further embodiments are set forth by the dependent claims 12 to 19.

DESCRIPTION OF THE DRAWINGS

The invention will be described in form of a preferred embodiment by making reference to the accompanying drawings, in which:

FIG. 1 demonstrates a top view of an autonomous device in form of an embodiment showing a vacuum-cleaning robot equipped according to the present invention;

FIG. 2 shows a side view of the autonomous device according to FIG. 1;

FIG. 3 shows a front view of the autonomous device illustrating the transmitter member at the front and two rows of receiving sensors;

FIG. 4 illustrates the double transducer element placed behind a wire mesh in front of the device;

FIG 5 is an enlarged horizontal cut of the transducer element of FIG. 4 through one of the transmitter strips;

FIG. 6 illustrates a simplified transmitter driving and switching circuit for the transducer element of FIG. 4;

FIG. 7 illustrates horizontal radiation patterns for the ultrasonic wide and narrow strip-shaped transducers of FIG. 4;

FIG. 8 illustrates vertical radiation patterns for the wide strip-shaped transducer element of FIG. 4; and

FIG. 9 illustrates vertical radiation patterns for the narrow strip-shaped transducer element

DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

General features

Figure 1 illustrates in a three dimensional top view an illustrative embodiment of an autonomous vacuum-cleaning device 1, which by itself will move on a floor and vacuum-clean a room. In the front portion there is arranged an ultrasonic transmitter 10. The transmitter consists of strip-shaped ultrasonic elements 21 and 22 having a length covering of the order 180° of the front perimeter of the device as illustrated in Figures 2 and 3. As seen in Figure. 2, the transmitter 10 with strip-shaped elements is mounted above a lower first row of microphone units 12. Above the strip-shaped transmitter elements a second row of microphone units 13 is localized. The ultrasound echo sensor microphones 12 and 13 together with the transmitter 10 form an ultrasonic sonar system for the navigation of the device. In the illustrative embodiment the transmitter transducer is countersinked in a forward directed, movable bumper unit 16. The bumper 16 controls a left and a right bumper touch sensor, either one being actuated if the bumper makes contact with an obstacle. In Figures. 2 and 3 it will be seen that the device has two diametrically positioned wheels 17, 18. The wheels 17, 18 are each independently driven by a separate motor preferably equipped with a gearbox. The driven wheels 17 and 18 will enable the device to also rotate around its own symmetry center or around either wheel 17, 18. On the axis from each motor driving the respective wheel 17 and 18 a respective quadrature sensor is mounted. Quadrature signals from the sensors are connected to a built-in microprocessor controlling the device. The signals from these sensors, or

equivalent devices, will be used for obtaining a dead count for estimating the distance of travel. Optional wheels support the back of the device. The device is generally balanced with a slightly larger weight on the rear half of the device, carrying for instance the batteries, such that it will always move with all wheels in contact with the floor. Due to this balancing the device may easily climb the edges of floor carpets and the like.

Ultrasound transducer

In Figure 4 is demonstrated an embodiment of the ultrasound transducer used for the ultrasound transmitter 10 in the front of the autonomous device 1. The ultrasound transducer consists of two strip-shaped elements 21 and 22 on a base material 11 presenting a length covering the inside of the front wire mesh opening of the autonomous device 1. The base foil 11 is further provided with a portion 24 carrying a connector 25 for electrical leads to the transducer elements 21 and 22.

Figure 5 illustrates a horizontal cross section of either of the two strip-shaped elements 21 and 22. An arrow indicates the transmit direction in Figure 5. The ultrasound element forming the semicircular electrostatic film-transducer consists of a thin membrane 30 of a metallized foil, for instance a PET-foil or the like. The foil carrying a thin metallic layer 31 forms the membrane in front of a thin air gap 32. The air gap separates the membrane from a second conducting layer 34. The carrier base material 35 with the conducting layer 34 is further on its opposite side coated with another layer 36. The second layer of conducting will act as a further screening of the back of the transducer elements which by the metallic layers 31 and 34 will act as a capacitor with the PET foil of the membrane 30 and air gap 32 as a dielectric. The second additional conducting layer 36 is further coated with an insulating dielectric layer 37. The metallized PET-foil should preferably not be thicker than 5 μm. In a preferred embodiment the metallic layer is a 5-100 nm layer of gold. The very thin air gap 32 is of great importance for the performance of the present ultrasound transducer, therefore the roughness of the layer 34 will be essential to maintain the thin air gap 32.

The transducer strips 21 and 22 are driven by an ultrasound generator controlled by a microprocessor 40. Figure 6 illustrates a simplified diagram of an embodiment of the ultrasound generator. In the illustrative embodiment a Motorola MC68332 processor is utilized, but other integrated low power microprocessors may be used by suitably adapting the software for the autonomous device. The CPU 40 of Figure 6 delivers a set of square pulses at a frequency of 30 kHz to a driver consisting of a field effect transistor. The drain of the field effect transistor has its voltage supply via the primary winding of a transformer having two secondary windings feeding the respective ultrasound element 21 and 22. Either one of the ultrasound transmitting elements will receive the electrical drive signal, which will be doubled to a 60 kHz ultra sound signal since the transducer element is rectifying. Thus the generated sound will be twice the frequency of the input signal. In the illustrative embodiment the signal consists of three periods of 30 kHz with a duty cycle of 40% generated from a Time Processor Unit (TPU) of the microprocessor. The TPU then runs in a mode referred to as Queued Output Mode (QOM). The microprocessor 40 will connect to ground either the control signal TXNEN- to the switch 42 for element 21, TXN for a narrow vertical transmission or the control signal TXWEN- to switch 44 for the wide vertical transmission element 22, TXW. Changing the programming of the QOM function parameters can vary frequency, duty cycle and number of pulses in the transmitted burst.

The physical horizontal shape of an element strip of the transducer generates a beam pattern with a wide horizontal distribution. Figure 7 illustrates a diagram for the horizontal distribution of the ultrasound waves from the transmitter 10. Both the narrow and the wider strip get a similar horizontal distribution. Figure 8 illustrates a vertical distribution of the ultrasound transmitted from the wider strip. The reason for the compressed lobe is that the wider strip acts as a vertical array of transmitter elements. The different sized lobes in the diagram illustrates the vertical lobe at

different horizontal angles from the central forward direction of the wire mesh 10 at directions perpendicular to the semicircular wire mesh.

Figure 9 illustrates corresponding vertical beam patterns for the narrow strip transducer. Also the maximum forward power output will be lower for the narrow strip producing the wider vertical pattern distribution. In other word the radiation pattern according to Figure 9 is suitable for near field navigation in combination with both the lower and upper rows of sensor microphones 12 and 13, while the radiation according to Figure 8 is excellent for sensing more distant obstacles mainly using the lower row of sensor elements 12.

Sensors for detecting the ultrasound transmitted by the ultrasound transducer may typically be Electret Condenser microphones The directivity of a naked microphone is almost omnidirectional. Therefore, according to the state of the art, the ultrasound sensor microphones are mounted behind a device containing a pair of vertical soundpipes in order to obtain a desired directivity. With this arrangement of transmitting and receiving, echoes from the floor or ground as well for instance sharp edged carpets or the like will be heavily suppressed. This gives a much more simplified detection of objects in the zone near to the device, where echoes from a floor or ground and the device itself are strongest.

It will be obvious to a person skilled in the art that the present transducer may be modified and changed in many ways without departing from the scope of the present invention, which is defined by the appended claims.

CLAIMS

1. A proximity sensing system for an autonomous device (1) provided with motor driven wheels and comprising an ultrasound transmitting member and receiving members which are connected to a microprocessor controlling the motions of the autonomous device by means of echo signals from the transmitter member received by the receiving members, **characterized in** that

the transmitter member (10) constitutes a double ultrasound transducer containing two separately driven strip-shaped elements forming a single semicircular unit positioned at a front of the autonomous device;

a first strip-shaped element of the ultrasound transducer forms a first elongated wide film-strip (21) generating a horizontally wide and vertically narrow beam at an optimum acoustic signal level output;

a second strip-shaped element of the ultrasound transducer forms a second elongated narrow film-strip (22) generating a horizontally wide and vertically wide beam;

whereby receiving members are arranged for receiving signals transmitted by the ultrasound transducer and reflected from surroundings of the autonomous device.

2. The system according to claim 1, **characterized in** that a first row of lower receiving members (12) and a second row of upper receiving members (13) are arranged for receiving signals transmitted by the ultrasound transducer and reflected from surroundings of the autonomous device.

3. The system according to claim 1, **characterized in** that the first (21) and second (22) strip-shaped element of the ultrasound transducer constitute capacitance film-transducers utilizing as a membrane a metallized foil (30) presenting a thin layer of the order 5 μm or less and a thin air gap (32) in front of a second metallic layer (34).

4. The system according to claim 3, **characterized in** that the metallized foil layer of the strip-shaped elements (21, 22) of the ultrasound transducer is a thin layer of an environmentally stable metal.

5. The system according to claim 3, **characterized in** that the metallized foil (30) of the strip-shaped elements of the ultrasound transducer is provided with a layer of gold (31).

6. The system according to claim 5, **characterized in** that the metallized foil layer of gold is of the order 5-100 nm.

7. The system according to claim 3, **characterized in** that the second metallic layer constitutes a first conducting layer (34) onto a base material provided on an opposite side with a second conducting layer (36) covered by a dielectric layer (37), the second conducting layer acting as an electrical screening of the back of the transducer.

8. The system according to claim 1, **characterized in** that the transmitter member (10) controlled by the microprocessor operates in an ultrasound frequency range around 60 kHz thereby avoiding general noise generated for instance by personal computer monitors.

9. The system according to claim 2, **characterized in** that the lower receiving members (12) and upper receiving members (13) constitute ultrasound microphone units provided with hollow pipes to further improve a directivity pattern for each ultrasound microphone unit.

10. The system according to claim 2, **characterized in** that one ultrasound microphone in the first row of lower receiving members (12a) is positioned directed to one side of the autonomous device to be used in a wall tracking operation.

11. An ultrasound transducer for a proximity sensing system, **characterized by**

a first strip-shaped element (21) of the ultrasound transducer driven by an ultrasound generator forms a first elongated wide film-strip generating a horizontally wide and vertically narrow beam at an optimum acoustic signal level output;

a second strip-shaped element (22) of the ultrasound transducer driven by the ultrasound generator forms a second elongated narrow film-strip generating a horizontally wide and vertically wide beam;

the first strip-shaped element (21) and second strip-shaped element (22) forming one integrated transmitting device (11).

12. The ultrasound transducer according to claim 11, **characterized in** that the first strip-shaped element (21) and second strip-shaped element (22) forming one integrated transmitting device (11) being placed above a first row of lower receiving members (12) and below a second row of upper receiving members (13) receiving signals transmitted by the ultrasound transmitter (10) and reflected from surroundings of the autonomous device.

13. The ultrasound transducer according to claim 11, **characterized in** that the first (21) and second (22) strip-shaped element of the ultrasound transducer constitute capacitance film-transducers with a membrane of a metallized foil (30) presenting a thin layer (31) of the order 5 μm or less and a thin air gap (32) in front of a second metallic layer (34).

14. The ultrasound transducer according to claim 11, **characterized in** that the metallized foil layer of the strip-shaped elements of the ultrasound transducer is a thin layer of an environmentally stable metal.

15. The ultrasound transducer according to claim 11, **characterized in** that the metallized foil (30) of the strip-shaped elements of the ultrasound transducer is provided with a layer of gold.

16. The ultrasound transducer according to claim 15, **characterized in** that the metallized foil layer of gold is of the order 5-100 nm.

17. The ultrasound transducer according to claim 11, **characterized in** that the second metallic layer (34) constitutes a conducting layer onto a base material (35) provided on an opposite side with a third layer (36) constituting a conducting layer covered by a dielectric layer (37), the third layer (36) acting as an electrical screening of the back of the transducer.

18. The ultrasound transducer according to claim 11, **characterized in** that one strip-shaped element at a time is driven by the ultrasound generator by means of a pair of switches (42, 44) controlled by a microprocessor (40) also used for processing signals acquired by the proximity sensing system.

19. The ultrasound transducer according to claim 11, **characterized in** that the first strip-shaped element (21) and second strip-shaped element (22) cover an forward proximity sensing angle of more than 150 degrees, and up to the order of 180 degrees.

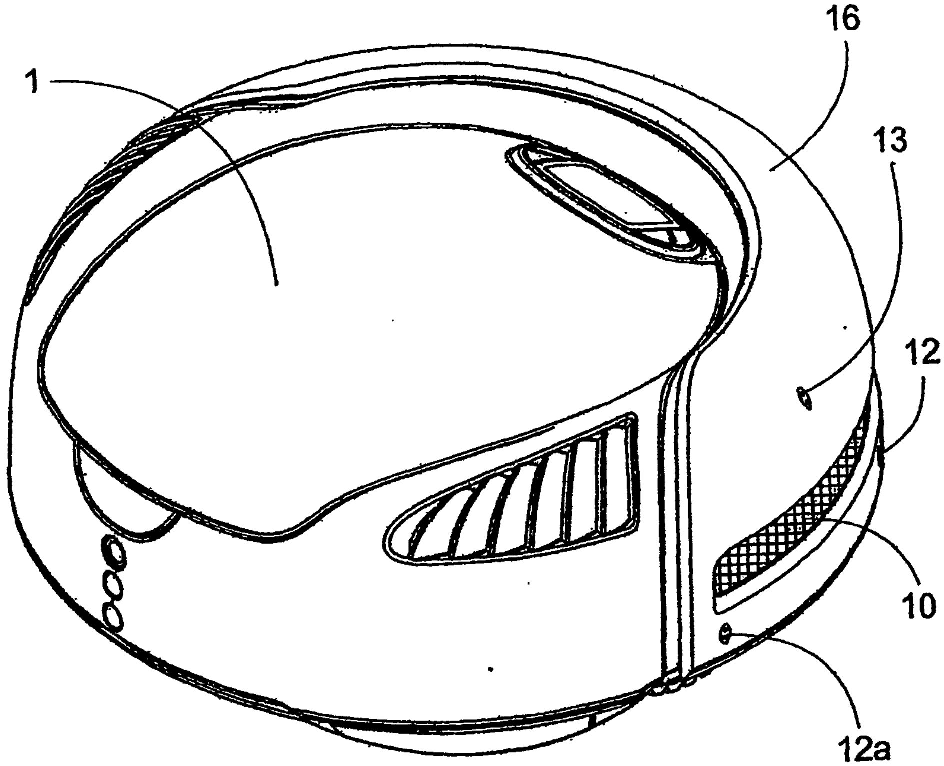


Fig. 1

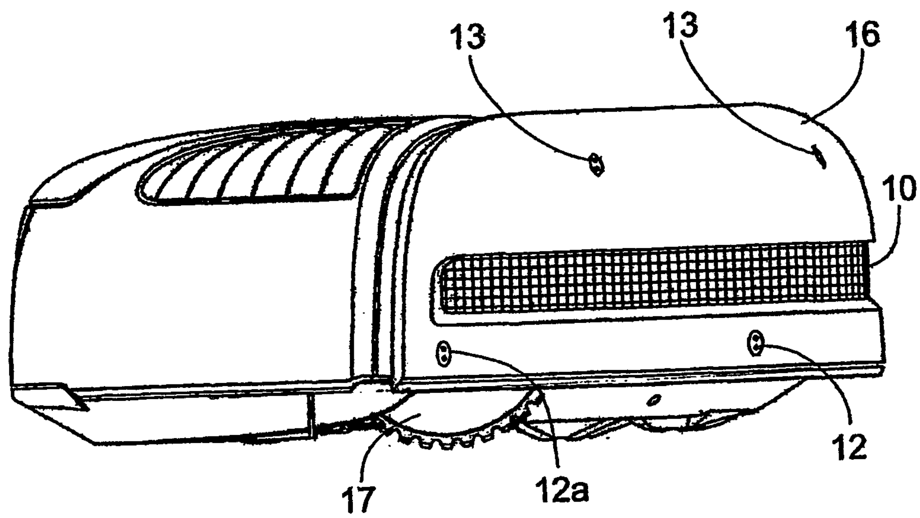


Fig. 2

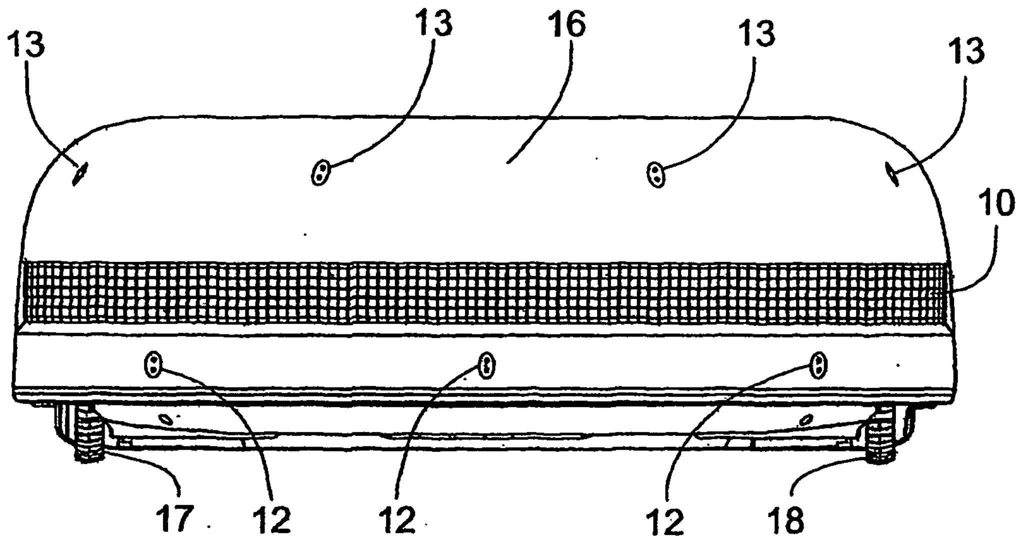


Fig. 3

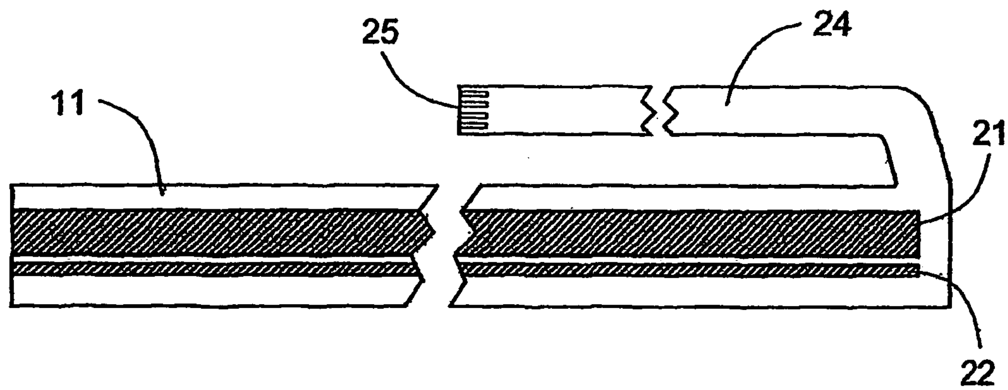
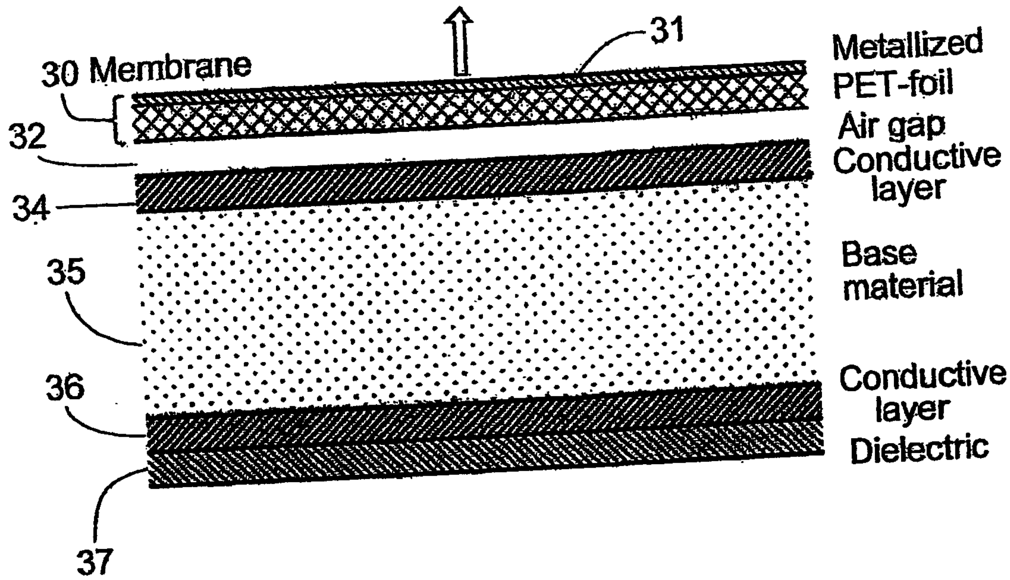


Fig. 4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30 Membrane
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Air gap
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Dielectric
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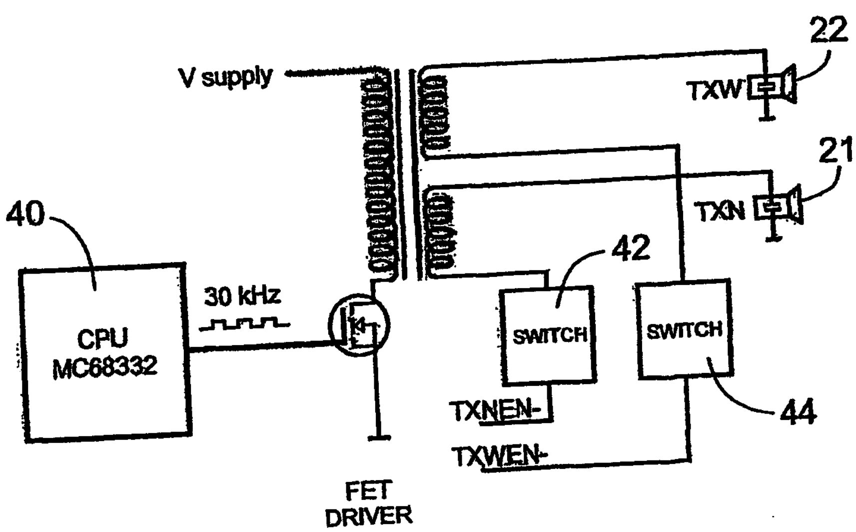
Fig. 5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SWITCH
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TXNEN-
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TXWEN-
FET DRIVER

Fig. 6

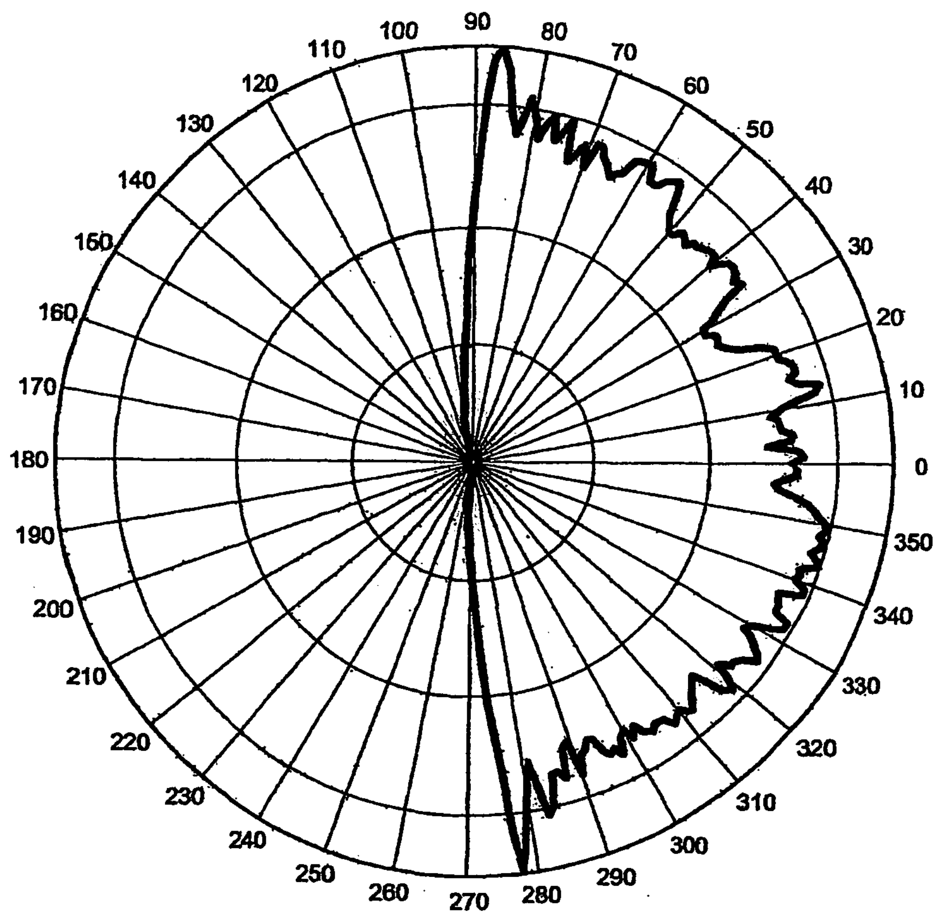
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Fig. 7

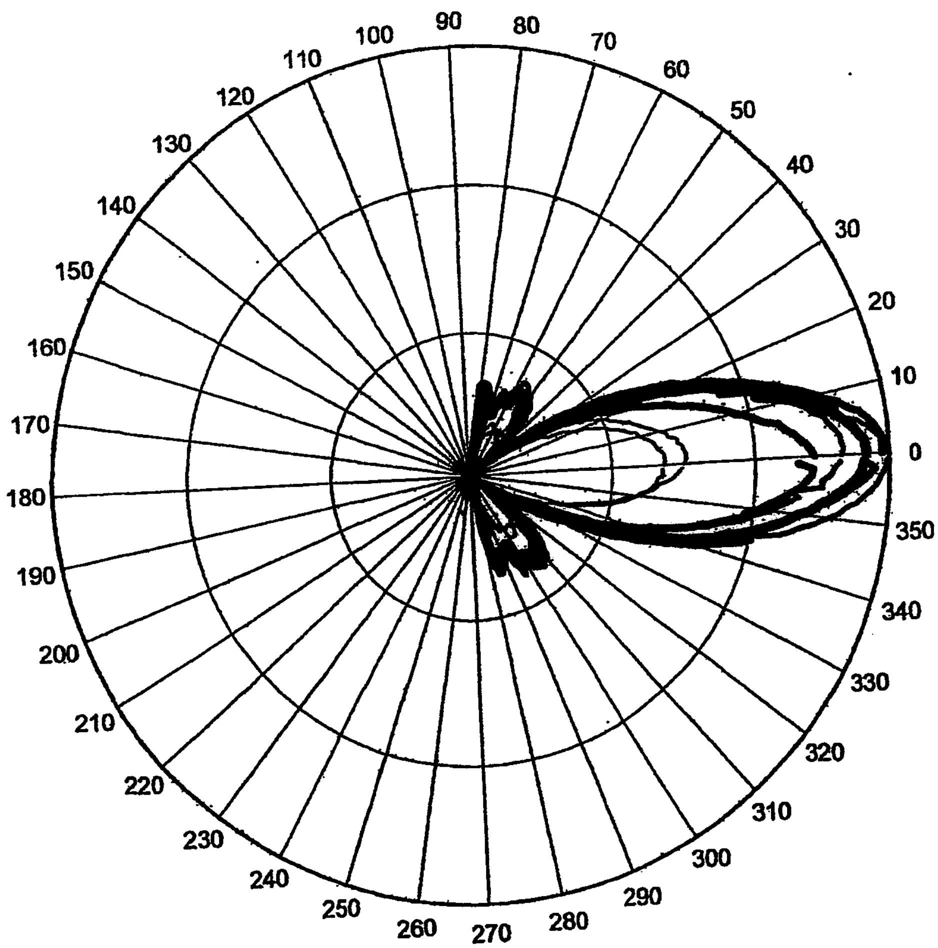
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Fig. 8

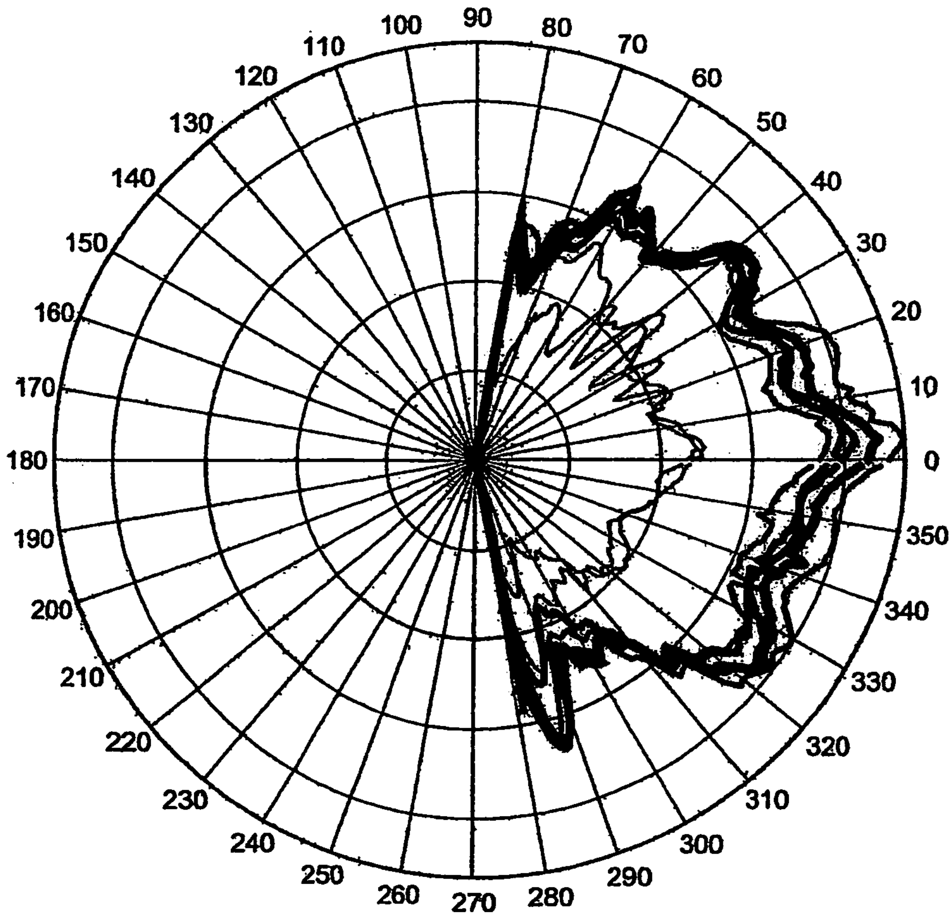
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Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 02/00421

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01S 15/93, G05D 1/03

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01S, G05D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9741451 A1 (AKTIEBOLAGET ELECTROLUX), 6 November 1997 (06.11.97), abstract --	1-19
A	WO 0038029 A1 (NOTETRY LIMITED), 29 June 2000 (29.06.00), abstract -- ---------	1-19

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 May 2002	18 -06- 2002
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Lars Jakobsson/mj Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

01/05/02

International application No.
PCT/SE 02/00421

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9741451 A1	06/11/97	AU 695722 B	20/08/98
		AU 713488 B	02/12/99
		AU 1155997 A	14/07/97
		AU 2795597 A	19/11/97
		BR 9612128 A	28/12/99
		CA 2225420 A	06/11/97
		DE 69706935 D,T	04/04/02
		EP 0835459 A,B	15/04/98
		EP 0977480 A	09/02/00
		ES 2165054 T	01/03/02
		HU 9900112 A	28/10/00
		IL 124927 D	00/00/00
		JP 11510935 T	21/09/99
		JP 2000514780 T	07/11/00
		NO 982721 A	14/08/98
		PL 327335 A	07/12/98
		SE 506907 C	02/03/98
		SE 9601664 A	31/10/97
		US 5935179 A	10/08/99
WO 0038029 A1	29/06/00	AU 1790200 A	12/07/00
		EP 1149333 A	31/10/01
		GB 9827779 D	00/00/00